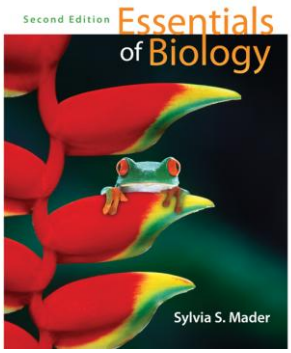


Essentials of Biology

Sylvia S. Mader

Chapter 5
Lecture Outline

The Dynamic Cell

You'd have to run about 14 miles to burn the calories from a pepperoni pizza.

A handful of peanuts contains enough energy to boil a quart of water.

It takes about 10 million ATP molecules per second to power an active muscle cell.

About 75% of the energy generated by a car's engine is lost as heat.

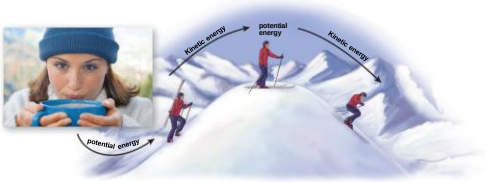
Stonewashing Without the Stones!!

- Stonewashing jeans with pumice stone can damage the fabric.
- The enzyme ***cellulase*** is used to achieve better results.
- What does ***cellulase*** digest?

5.1 What Is Energy?

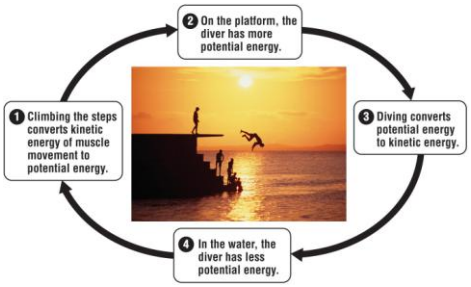
- Energy is the capacity to do work.
- Where does our biosphere gets its energy from?
- 2 basic forms of energy
  - **Potential energy** – stored energy
  - **Kinetic energy** – energy of motion
  - 2 forms are converted back and forth

Figure 5.1 Potential energy versus kinetic energy



1st Law: Law of Conservation of Energy

- Energy can be changed from one form to another, but it cannot be created or destroyed.



2nd Law: The universe increases in Entropy

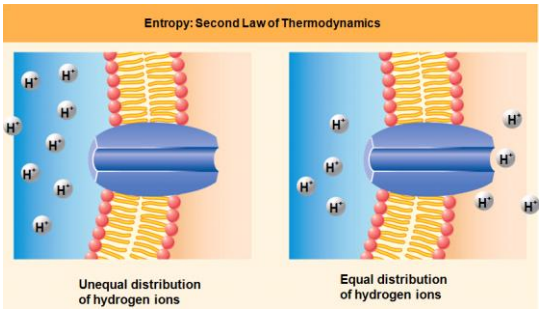
- Energy cannot be changed from one form to another without a loss of usable energy
  - Heat is the least usable form of energy
- **Heat is due to the *motion* of molecules**
  - Is a type of kinetic energy.
  - Is a product of all energy conversions.
- As usable energy decreases and unusable energy increases, "***entropy***" increases

Entropy

- ***Entropy*** is a measure of *disorder*, or *randomness*.
- All energy conversions increase the entropy of the universe.
- ***Only way to maintain or bring about order is to add energy***

Figure 5.2a Entropy

Figure 5.2b Cells and Entropy

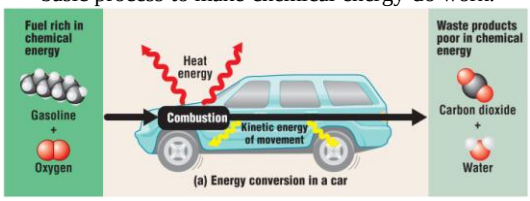


Entropy

- Our universe is a closed system
  - All energy transformations increase the total entropy of the universe
- Energy from the sun allows plants to make glucose from the more disorganized water and carbon dioxide
  - Some of sun's energy lost as heat

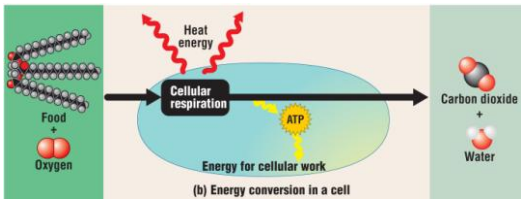
Chemical Energy

- Chemical energy
  - Form of potential energy.
  - Found in food, gasoline, and other fuels.
- Living cells and automobile engines use the same basic process to make chemical energy do work.



Chemical Energy

- Living cells and automobile engines use the same basic process to make chemical energy do work.



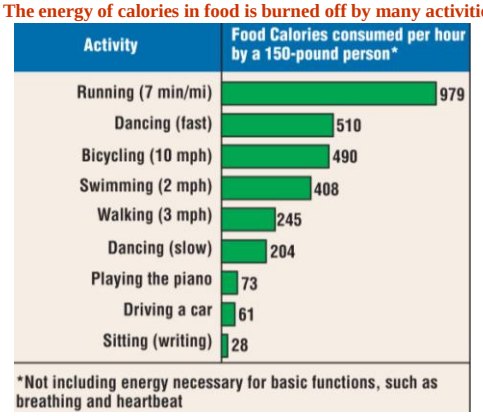
Cellular Respiration

- Cellular respiration
  - Energy-releasing chemical breakdown of fuel molecules.
  - Provides energy for the cell to do work.
- Measuring Energy…
  - What's a calorie?

Measuring Energy in Food Calories (kcal)

- Food energy measured in calories
- ***calorie*** – amount of heat required to raise temperature of 1 gram of water by 1°C
- Kilocalorie (kcal) or **Calorie = 1,000 calories**
  - Value listed on food packages

The energy of calories in food is burned off by many activities.



5.2 ATP—Energy for Cells!

Adenosine triphosphate

- Energy currency for cells
- Cells use ATP to carry out nearly all activities
- 3 phosphate groups makes it unstable
- Easily loses a phosphate group to become ADP (adenosine diphosphate)
- Continual cycle of breakdown and regeneration

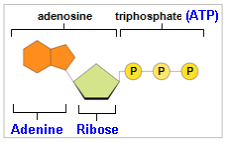
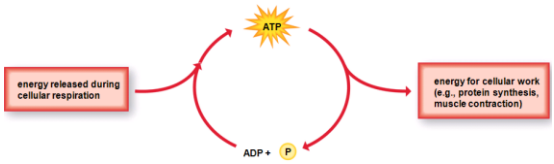


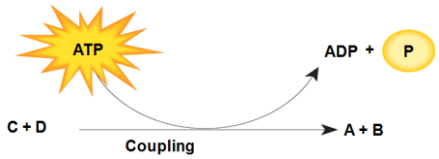
Figure 5.3 ATP

Figure 5.4 The ATP cycle



- ATP releases energy quickly
  - One active muscle cell needs about 10 million ATP per second!
- Amount of energy released is usually just enough for a biological purpose
- Breakdown can be easily coupled to an energy-requiring reaction

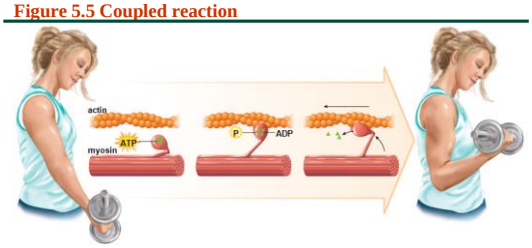
Coupled Reactions



Coupled reactions

- Energy-releasing reaction can drive an energy-requiring reaction
- Usually energy-releasing reaction is ATP breakdown

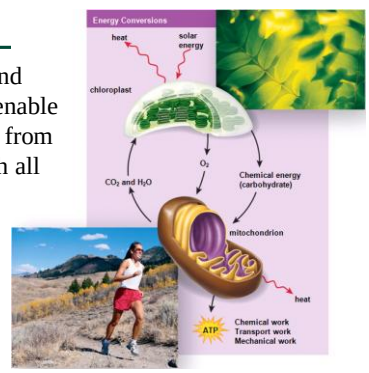
Figure 5.5 Coupled reaction



- ATP breakdown provides the energy for muscle movement
- Myosin combines with ATP
- ATP breaks down
- Release of ADP + P causes myosin to change shape and pull on actin filament

Flow of Energy

- Chloroplasts and mitochondria enable energy to flow from the sun through all living things



Flow of Energy

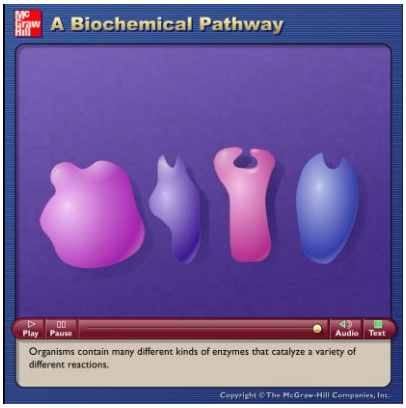
- **Photosynthesis** – solar energy used to convert water and carbon dioxide into carbohydrates
  - ✓ Food for plants and other organisms
- **Cellular respiration** – carbohydrates broken down and energy used to build ATP
  - ✓ Useful energy is lost with each transformation
- Living things dependent on constant in/out of solar energy

5.3 Metabolic Pathways and Enzymes

- Metabolism is the sum total of all chemical reactions that occur in an organism.
- Most metabolic reactions need an enzyme
- Metabolic Pathway….

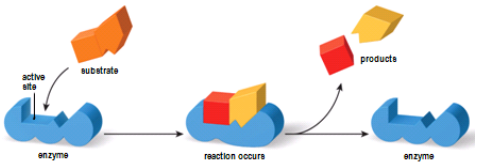
$$A \xrightarrow{E_1} B \xrightarrow{E_2} C \xrightarrow{E_3} D \xrightarrow{E_4} E \xrightarrow{E_5} F \xrightarrow{E_6} G$$

  - Product of a previous reaction becomes the reactant of the next reaction
  - **Substrates:** _____????_____
  - **Enzymes:** _____????_____
    - Protein catalyst that speeds up a reaction without being used up
    - Enzymes are reaction specific (i.e. Each reaction requires its own enzyme) **Why?**



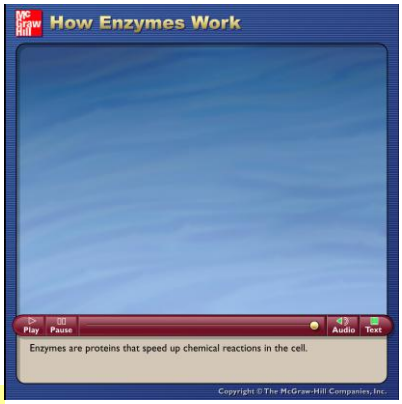
A Biochemical Pathway

Figure 5.8 Enzymatic action



Enzymes

- Act on substrates
- Facilitate breakdown or synthesis reactions
  - ✓ i.e. catalyze hydrolysis or dehydration synthesis reactions



How Enzymes Work

How does an enzyme speed up a reaction?

Enzyme's Active Site

- Accommodates substrate
- **Lock and Key Model** – only one key wil fit!
  - ✓ Lock = ??
  - ✓ Key = ??
- **Induced fit model** – undergoes slight shape change to accommodate substrate
  - ✓ Like a hand and glove
  - ✓ Active site returns to original shape after releasing product(s)
  - ✓ Enzymes are not used up by the reaction

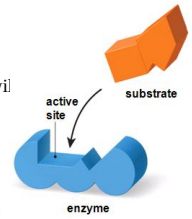
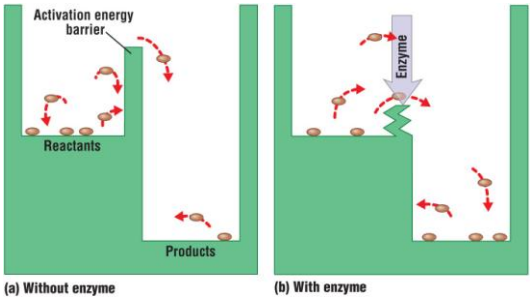


Figure 5.8

Activation Energy

- Molecules often do not react with each other unless they have enough kinetic energy.
- **Energy of activation** (E_a)
  - energy needed for molecules to react with one another
  - Triggers a chemical reaction to proceed.
- **Enzymes**
  - ***Lower*** **the E_a** of chemical reactions
  - Bring substrates into contact to react

- A LOWER barrier is easier/ faster to get over
- A LOWER E_a makes a reaction easier/ faster



E_a Lowering

- A LOWER barrier is easier/ faster to get over
- A LOWER E_a makes a reaction easier/ faster

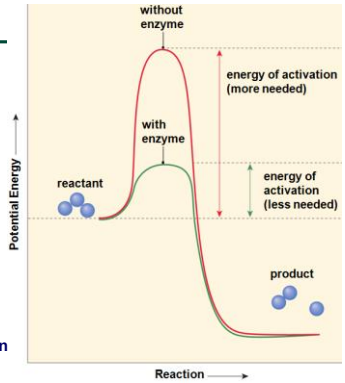
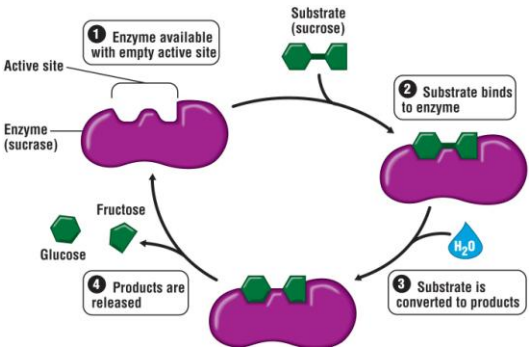
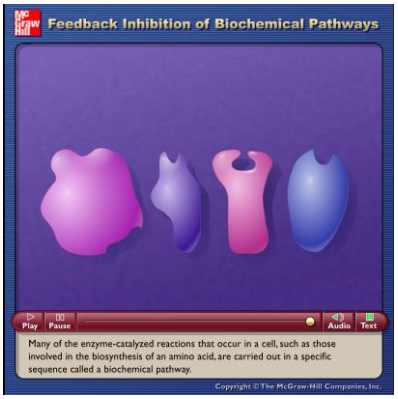


Figure 5.10
Energy of activation

Enzymes can function over and over again.



Controlling Metabolism: Feedback inhibition



Controlling Metabolism: Feedback inhibition

Enzyme inhibition

- Occurs when an active enzyme is prevented from combining with its substrate
  - ***Cyanide*** binds to and inhibits enzymes (a poison!!)
  - ***Penicillin*** interferes with a bacterial enzyme which kills the bacteria
- ***Feedback inhibition***
  - An end product of a pathway inhibits the *1st enzyme* in the pathway
  - binds to site other than active site t
  - Causes enzyme to change shape
    - End result???

Figure 5.9 Feedback Inhibition (1 of 3)

- Not enough produced!!
- Consequence?

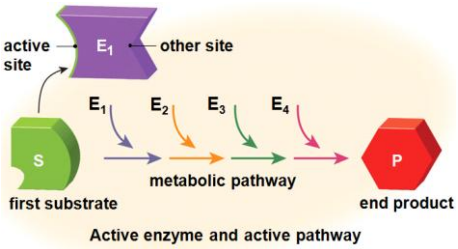


Figure 5.9 Feedback Inhibition (2 of 3)

- Product builds up—cell doesn't need more
- Product binds to enzyme and changes its shape
- Consequences??

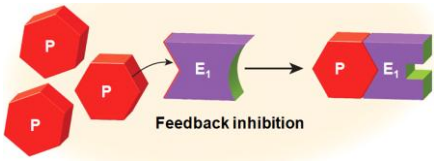


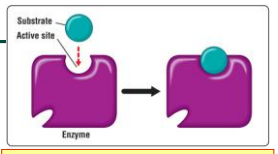
Figure 5.9 Feedback Inhibition (3 of 3)

- Now substrate can't bind to enzyme
  - ✓ **Consequences??**
- When product gets low, enzyme will go back to original shape.
  - ✓ **Consequences??**

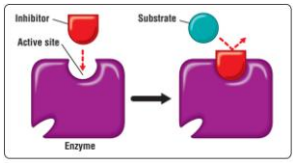
Another kind of inhibitor

Competitive Inhibitors

- Attach to active site of enzyme
- A molecular "imposter"
- Block access to active site
- Mechanism of many drugs



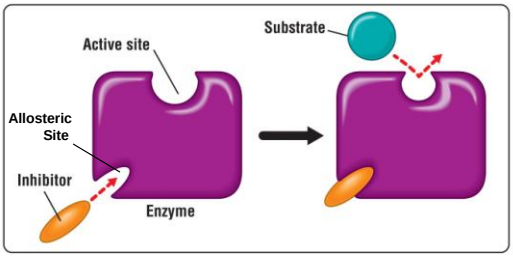
Enzyme & substrate binding normally



Enzyme inhibition by substrate impostor

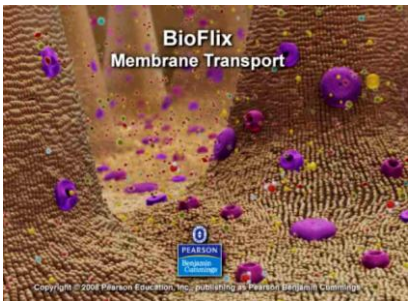
Negative Feedback Inhibition: Allosteric Inhibition

- Inhibitor binds to a site away from the active site



5.4 Cell Transport

- Plasma membrane regulates traffic in and out of cell.
- Selectively permeable
  - some substances pass freely, some prohibited
- 3 ways to enter
  - Passive transport
    - Substances move from *higher to lower* concentration
    - No additional energy required.
  - Active transport
    - Substances move from *lower to higher* concentration,
    - Requires additional energy (ATP)
  - Bulk transport
    - movement independent of gradient; additional energy required.



BioFlix: Membrane Transport

Passive Transport

- Molecules move down their concentration gradient until equilibrium is reached
- Cell does not expend additional energy – molecules already in motion
- Some molecules slip between phospholipids
- Facilitated diffusion – others use transport protein specific to molecule
- Water uses aquaporins – explains faster than expected transport rate

Simulation of Random Molecular Motion

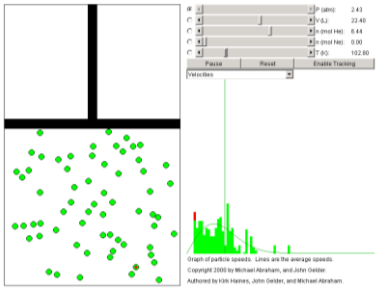
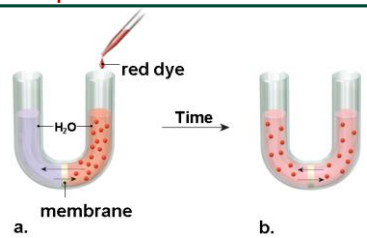
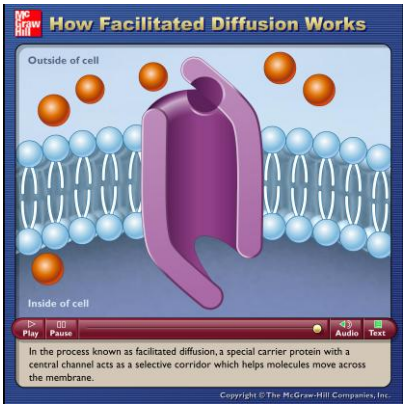


Figure 5.11 Simple diffusion demonstration



- Net movement of dye is to the left side of membrane
- At equlibirum, dye equal on both sides of membrane and net movement stops
- Solution – contains solute (dye or other substance) and solvent (water)

How diffusion works



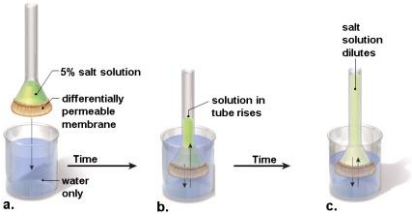
How facilitated diffusion works

Osmosis and Water Balance in Cells

- Osmosis is the passive transport of water across a selectively permeable membrane.
- Water moves from a ....
  a) Hypertonic to a hypotonic solution.
  b) Hypotonic to a hypertonic solution.
  c) Hypotonic to an isotonic solution.
  d) Hypertonic to an isotonic solution.
  e) I really don't know!

PLAY Osmosis

Figure 5.12 Osmosis Demonstration



- Osmosis
  - Diffusion of water across a ***semipermeable membrane***
  - Net movement of water **from beaker** (***higher water concentration***) **to tube** (lower water concentration)
  - Solution inside tube rises until equal concentration of water

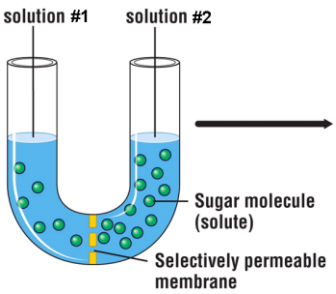
Osmosis: Important terms to remember!

- A ***hypertonic*** solution
  - Has a *higher* concentration of *solute*.
  - Therefore has a _____ concentration of H_2O
- A ***hypotonic*** solution
  - Has a *lower* concentration of *solute*.
  - Therefore has a _____ concentration of H_2O
- An ***isotonic*** solution
  - Has an equal concentration of solute.
  - Therefore has a _____ concentration of H_2O

Osmosis and Water Balance in Cells

- Osmosis is the passive transport of water across a selectively permeable membrane.
- Water moves from a ....
  a) Hypertonic to a hypotonic solution.
  b) Hypotonic to a hypertonic solution.
  c) Hypotonic to an isotonic solution.
  d) Hypertonic to an isotonic solution.
  e) I really don't know!

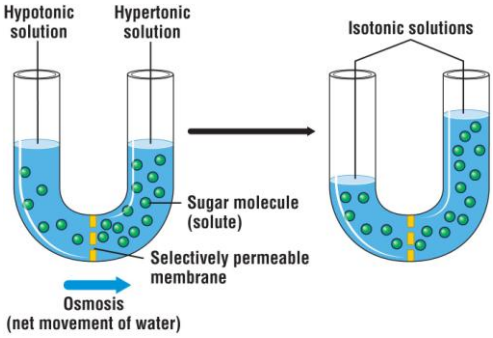
Osmosis—the diffusion of water!



Key Questions

1. Which solution is hypertonic? Which one is hypotonic?
2. What will happen to the water levels?
3. In which direction will the sugar molecules diffuse?

Osmosis—the diffusion of water!



Water Balance in Animal vs. Plant Cells—why the different?

The ability to balance water loss and water uptake is vital to life!

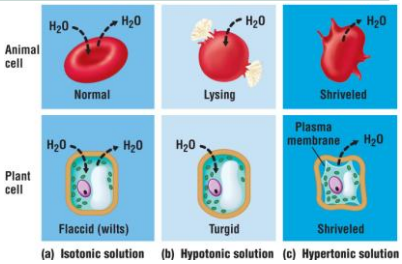


Figure 5.13 Osmosis in animal & plant cells

PLAY Plasmolysis

PLAY Turgid *Elodea*

Osmoregulation in Plant Cells

- Water balance in plant cells is different.
  - Plant cells have ***rigid cellulose cell walls***.
  - They are at the mercy of the environment. ☹

Cells in an Isotonic Solution

- Cell neither gains or loses water
- Concentration of water and solute the *same* on both sides of the membrane
- 0.9% saline isotonic to red blood cells
  - ***What's the % H_2O of the solution?***

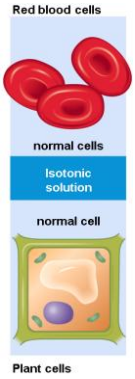


Figure 5.13 Osmosis in animal & plant cells

Cells in a Hypotonic Solution

- Concentration of water outside cell ____?____ than inside cell
- Cell ____?___ water
- Animal cells may lyse or burst
- Plant cells use this to remain ***turgid***

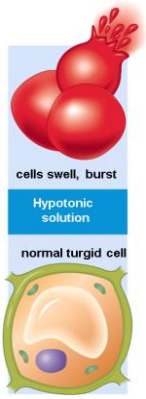


Figure 5.13 Osmosis in animal & plant cells

Cells in a Hypertonic Solution

- Concentration of water outside cell is ____?____than inside cell
- Cell ____?_____ water
- Animal cells shrink (***crenate***)
- Plant cells undergo ***plasmolysis*** and may wilt

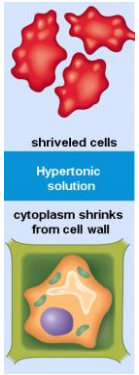
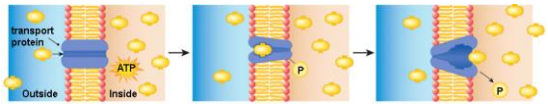


Figure 5.13 Osmosis in animal & plant cells

Active Transport—Pumping Molecules Across Membranes



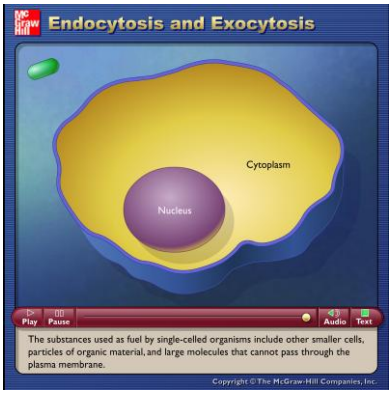
- Cells expend energy to move molecules ***against their concentration gradient***
- Requires ***transport protein and ATP***
- Sodium-potassium pump important in maintaining gradient of ions used in nerve impulse conduction

Figure 5.14 Active transport

PLAY Sodium-potassium pump

Bulk Transport—Movement of Large Molecules

- Macromolecules are too large to be moved by transport proteins
- ***Vesicles*** takes them in or out of cell
- ***Exocytosis***
  - Vesicles secrete substances outside of the cell
- ***Endocytosis***
  - Movement of substances into a cell

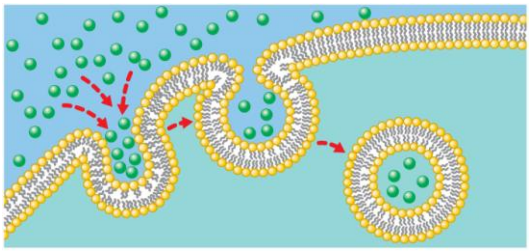


Endocytosis & Exocytosis

Endocytosis

- ***Phagocytosis—"cell eating"***
  - cell surrounds, engulfs and digests particle.
  - e.g.??
- ***Pinocytosis—"cell drinking"***
  - vesicle form around liquid or small particles.
- ***Receptor-mediated endocytosis***
  - triggered by the binding of external molecules to membrane proteins
  - selective and more efficient.

Figure 5.15b Endocytosis



(b) Endocytosis

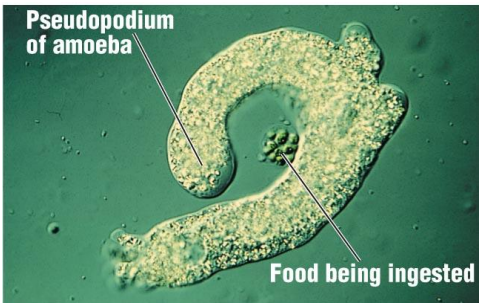
Endocytosis

- In phagocytosis ("cellular eating"), a cell engulfs a particle and packages it within a food vacuole.
- In pinocytosis ("cellular drinking"), a cell "gulps" droplets of fluid by forming tiny vesicles.

PLAY Phagocytosis

PLAY Pinocytosis

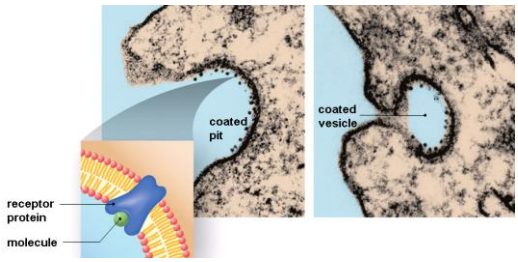
Phagocytosis in Amoeba



PLAY Amoeba phagocytosis

Figure 5.16 Receptor-mediated Endocytosis

- Triggered by the binding of external molecules to membrane proteins.



PLAY Receptor-Mediated Endocytosis

Receptor-mediated Endocytosis

- Removal of cholesterol from the blood by Low Density Lipoprotein Particle (LDL)

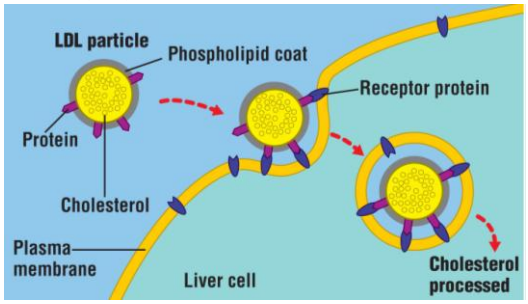
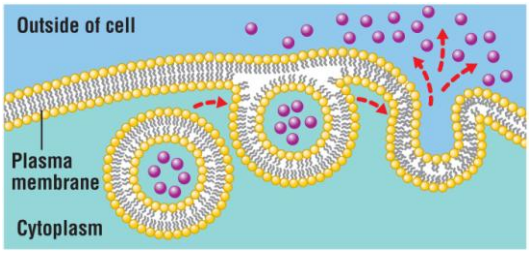


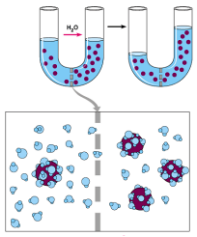
Figure 5.15a Exocytosis



(a) Exocytosis

Concept Check

This diagram represents osmosis of water across a semipermeable membrane. The U-tube on the right shows the results of the osmosis. **What could you do to level the solutions in the two sides of the right hand U-tube?**



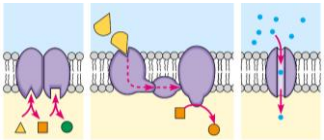
a. Add more water to the left hand side.

b. Add more water to the right hand side.

c. Add more solute to the left hand side.

d. Add more solute to the right hand side.

Concept Check



Membranes organize cell activities. The proteins imbedded in the membranes are essential to their function. These membrane proteins have properties that allow them to "float" in the membrane. **Which of the following describe those properties?**

a. The surface region of the protein in the interior of the membrane is mostly hydrophobic.

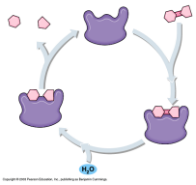
b. The surface region of the protein in the interior of the membrane is mostly hydrophillic.

c. The surface region exposed to the outer environment is hydrophobic.

d. The surface region exposed to the interior environment is hydrophobic.

Concept Check

Enzymes catalyze the many reactions in a cell. There are hundreds of different enzymes in a cell—each with a unique three-dimensional shape. **Why do cells have so many different enzymes?**



a. Each enzyme molecule can only be used once.

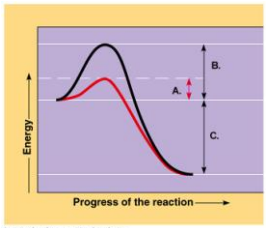
b. The shape of enzyme's active site generally fits a specific substrate.

c. The substrate molecules react with enzymes to create new enzymes.

d. Enzymes are randomly produced. With thousands of different shapes—one is likely to work.

Interpreting Data

In order to start a reaction a certain amount of energy must be absorbed by the reactants. This is called the energy of activation. **Which of the following is the normal energy of activation?**



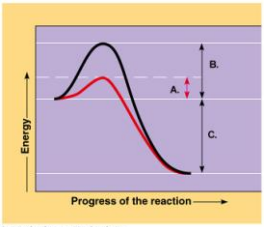
a. A.

b. B.

c. C.

Interpreting Data

Which of the following represents the energy of activation that is modified by an enzyme?



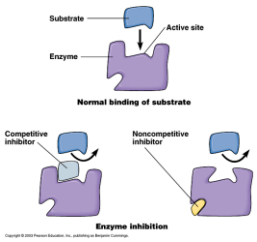
a. A.

b. B.

c. C.

Biology and Society

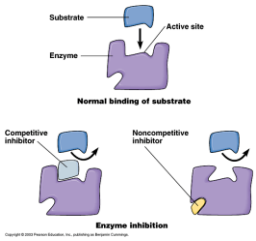
Many insecticides operate as permanent enzyme inhibitors. Organo-phosphate insecticides interfere with nerve transmission, affecting not only insects but also humans and other vertebrates. Use of such insecticides is carefully regulated and requires caution. **Is an unblemished and low cost food supply worth the risk of the pesticide use?**



Strongly Agree — A. B. C. D. E. — Strongly Disagree

Biology and Society

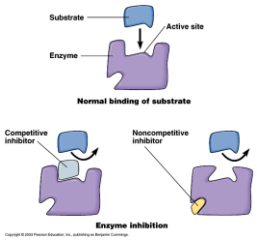
Many insecticides operate as permanent enzyme inhibitors. Organo-phosphate insecticides interfere with nerve transmission, affecting not only insects but also humans and other vertebrates. Use of such insecticides is carefully regulated and requires caution. **Would you be willing to pay a little more for slightly blemished but otherwise healthy food products—especially if pesticides were not used?**



Strongly Agree A. B. C. D. E. Strongly Disagree

Biology and Society

Many insecticides operate as permanent enzyme inhibitors. Organo-phosphate insecticides interfere with nerve transmission, affecting not only insects but also humans and other vertebrates. Use of such insecticides is carefully regulated and requires caution. **Do you think that regulation in the insecticide industry is appropriate?**



Strongly Agree A. B. C. D. E. Strongly Disagree